High-Gain Utility Amplifier

The TeachSpin SIM called 'High-Gain Utility Amplifier' is a double-width electronic module designed to amplify small d.c. or low-frequency voltages. It permits adjustment of the gain, or amplification, by factors of up to 10^3 in each of two stages. It also permits the addition of an 'offset' of either sign, of up to ±10 V, to the signal emerging from the first stage of amplification. Finally, it permits a choice of time constants for low-pass filtering, ie. time-averaging, of the output signal.

Features:

This SIM requires power from a SIM mainframe or 'crate' (or from TeachSpin's substitute power supply), and it derives all its power from that supply.

This SIM amplifies an input voltage presented at the front panel; it has two inputs adaptable to differential-mode detection, and it allows choices for the input impedance of each of them.

This SIM permits choices of first-stage gain, chosen from the range 1 - 1000.

To the first-stage-amplified signal may be applied a 'd.c. offset', of either sign, and of size up to 10 V.

The output of the first stage will also be time-averaged, with a choice of time-constants in the range 0.03 – 10 s.

The resulting d.c.-offset and time-averaged signal may be further amplified by another factor chosen from the range 1- 1000.

The 'output swing' of each stage is limited to the range of about ±12 V.

Layout:

Front panel features:

Two input BNC connectors, labelled + and -: either accepts a voltage (of either polarity), and the sign indication is to be understood as implying a first-stage output voltage of $V_1 = G_1 (V_+ - V_-)$.

Toggle switches above those inputs: each switch permits its corresponding BNC input to be fixed at ground potential, or set either to 10-MΩ or to much higher input impedance.

Monitor BNC connector: a voltage monitor of the output of the first stage of amplification (without filtering or offset).

Output BNC connector: the voltage output of the second stage of simplification.

Input gain: this rotary switch controls the gain of the first stage of amplification, in range 1 - 1000 in a 1-2-5 sequence.

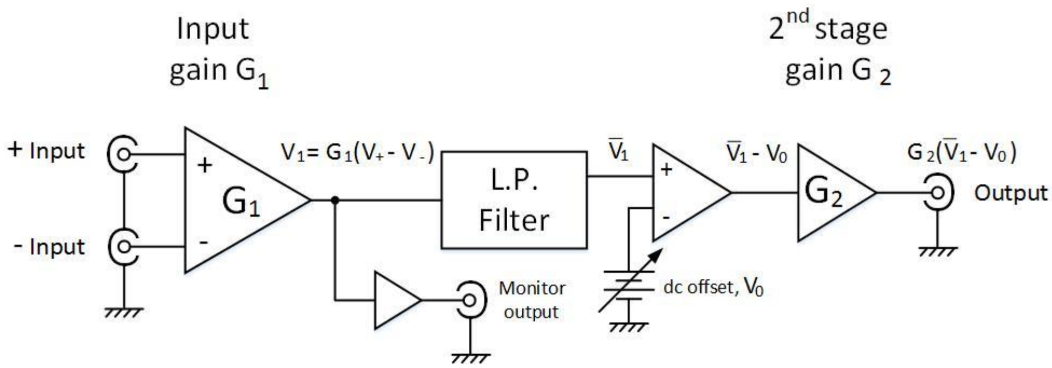
Time Constant: The output of the first stage of amplification, beyond its Monitor point, will be time-averaged using a one-pole or running-average filter, with time constant τ selected in the range 0.03 s to 10 s. (The -3-dB bandwidth of the amplifier's response accordingly is the frequency $1/(2\pi\cdot\tau)$; this varies from 5 Hz down to 0.016 Hz with the setting of τ.)

Offset Polarity: a 3-way toggle switch permits the addition, to the filtered first-stage output, of a d.c. offset voltage of zero, or of a sign selected here.

DC Offset: a 10-turn control permits selection of the size of the d.c. offset to be applied, in the range 0 - 10 V in magnitude.

Second Stage Gain: this rotary switch controls the gain of the second stage of amplification, in range 1 - 1000 in a 1-2-5 sequence. That gain is applied to the filtered and possibly d.c.-offset output of the first stage.

Block Diagram:



Operation:

This SIM provides a single channel of amplification of low-frequency voltage signals. The output voltage range is at least ±10 V, and the maximum gain available is $(10^3)^2$ or 10^6, meaning that a differential input voltage of just ±10 μV might drive the output over its full range. The SIM also applies some time-averaging (ie. low-pass filtering) in the amplification process, and allows a d.c. offset to be applied to the signal before final amplification.

Connections:

This SIM derives all its power from the SIM crate (or substitute power supply) into which it is plugged. Input, monitor, and output connections are all made via the *front* panel. The only back-panel connections are the standard connections to the crate's power supplies.

Power:

This SIM delivers at delivers at most ±20 mA of output current in the ±10-V range, so its output power is under 0.2 W. The SRS SIM crate makes available a total of 70 W to power all its SIMs, so there ought always to be enough power to operate the load of the high-Gain Utility Amplifier SIM.

Settings:

First-time users of this SIM might want to set the Time-Constant to its *minimum* value of 0.03 s, and set the Offset Polarity to the (central) OFF position. They might also want to pick low gains, perhaps 1, 3, or 10, for each stage.

The amplifier stages are both d.c. coupled, so they will amplify voltages down to zero frequency. The upper frequency 'limit' (ie. the -3-dB point for its a.c. response) is *at most* 5 Hz, so this amplifier is *not* suited to 'audio' waveforms.

For amplification of a single-ended voltage, apply the signal to the + Input, and set the 3-way toggle switch above the – Input to GND = ground potential.

For amplification *with inversion*, apply the signal to the - Input, and set the 3-way toggle switch above the + Input to GND = ground potential.

For differential-mode amplification, apply signals both to the + Input and to the – Input, and use the GND setting on *neither* of the input toggle switches. Either input may lie anywhere in the range (-10, +10) Volts, and the first-stage output will be given by the amplified difference, $G_1 \cdot (V_+ - V_-)$.

Inputs that are not grounded may be set so as to present to the source either a 10-MΩ, or a much higher, input impedance. For the High-impedance selection, the source needs to provide some d.c. current path to ground (for the passage, to ground, of the tiny 'input bias current' of the amplifiers).

Activation:

The whole SIM is activated as you've as you've energized the SIM crate or equivalent that is powering it. Operation at too high a gain may result in the Output saturating at a 'rail' near ±12 V (if the inputs are left open, or if d.c. offsets are uncorrected) or may even cause the Output to oscillate (if there is some feedback, or coupling, from output back to input).

Application:

This amplifier is designed for that common laboratory task of seeing (and amplifying) small changes in an otherwise steady, but non-zero, voltage. Merely as a concrete illustration of that general task, here we imagine a temperature transducer whose voltage output (at an absolute temperature near 200 K) might be +650 mV. Now we imagine looking for a 0.1-K increase in temperature, which might give a decrease, by about 0.2 mV, in that 650-mV voltage.

In order to make visible that change of -0.2 mV or -200 μV, one might be tempted to apply a mere amplification, perhaps by 20-fold. Then an amplified change of 20 × -0.2 mV = -4 mV should result. But that -4-mV change will lie atop the 20-fold amplification of the 650-mV voltage, which is 13 V (and this might saturate the output of the amplifier, and/or the input of whatever is measuring the amplifier's output).

Here's a better strategy. We want to be able to see, with good sensitivity, the difference between results (650 - 0) mV and (650 - 0.2) mV, subject to the requirement of keeping voltages in the ±10-V range. So we apply our (single-ended) voltage to the + Input, and we set the – Input to GND = ground. (A choice of High, rather than 10-MΩ, input impedance at the + Input might be appropriate – that depends on the transducer.) Now we limit the Input Gain or first-stage amplification to 10-fold.

The output of the first, or input, stage, will then lie in the range (6.5 - 0) V to (6.5 - 0.002) V. (This voltage will be directly visible, prior to any offset or filtering, at the Monitor output of the amplifier.) Note the 10-fold amplification of the temperature-change signal of interest (from 0.2 to 2 mV), and note that the first-stage output now stays within the ±12-V 'rails' of the amplifier system.

Next that first-stage output may be filtered, by taking a 'running average' over a time interval, of duration τ, into the past. The larger the time constant, the more the noise will be filtered away from the signal; but the larger the time constant, the slower will be the response to any change. (Note that it takes about 5 time-constants' worth of waiting to get a >99%-complete response to a step change in the signal, so the use of large time constants will require long waits for equilibration.)

To permit further amplification of the signal requires dealing with the tranducer's large steady output value (of over 600 mV) that accompanies the interesting but small change (of only -0.2 mV). In this case, we'd like to subtract a constant 6.00 (or 6.40, or even 6.49) V from the 6.50-V output of the first stage. To do so, we'd set the Offset Polarity to -, and dial the 10-turn DC Offset control up to 6.00 (or 6.40, or 6.49) turns on its 10-turn dial. The result of the offset correction will be a steady level of no longer 6.50 V, but rather 0.50 (or 0.10, or 0.01) V. But the full 10-fold-amplified change, of size -2.0 mV = -0.002 V will still be present atop this now-much-smaller voltage.

So now the Second-Stage Gain may be set to 10 (or, with larger offset, to even higher gain settings). For a d.c. offset of 6.00 V, and a 'leftover' of a steady 0.50 V subject to a -2 mV signal, a gain of 10 gives a steady level of 5.0 V subject to a -20 mV signal. That is to say, the temperature change will show up as a 5.00-V reading changing to 4.98 V.

If the transducer's 'background level' near 650 mV at the input is stable enough, you can dare to offset a larger fraction of it, and use a still-higher gain in the second stage. A 6.49-V offset (after the ×10 first-stage amplification) leaves a 0.01-V or 10-mV steady value, still subject to a -2-mV change to 8 mV. Now you might use a gain of 500 for the second stage, so a steady result of 500 × 0.01 V or +5.0 V would change to 4.0 V, for a full volt of change at output in response to that tiny +0.1 K temperature change.

Note in this case that a change at the input of -0.2 mV has been transformed by factor $G_1 \cdot G_2$ = 10·500 = 5000, to a change at the output of (-0.2 mV)(5000) = -1.0 V. Or working in reverse, any change of ΔV seen at the output stands for a known change, of ΔV /5000, at the input. The amplification factors are chosen and reliable numbers, and their size does not change with settings of the d.c. offset (if any).

Note too that the amount of gain you can use depends on the steadiness of the d.c. level you are trying to offset, and jointly on the noise present in the input signal, and the noise contributed by the amplifiers. To see the effect of the latter, set both inputs to their GND or ground position, set both stages' gains to 10^3, set the time constant to τ = 0.03 s, and set the d.c. offset control to give the output an average value near zero. (At this level of gain, you'll find that offset adjustment is quite 'twitchy'.) View the result using a 'scope set to perhaps 500 mV/div vertically, and perhaps 1 s/div horizontally. You're looking at the *million-fold amplified* version of the input-stage noise of the amplifier, filtered to the 0 – 5 Hz bandwidth. Every 500 *nano*Volt or 0.5 μV change in the effective voltage at the input of the amplifier causes a full division of vertical change on your 'scope. Any actual signal you hope to detect would have to compete with the noise, ie. the fluctuations, you are already seeing.